HIGH VOLTAGE POWER SUPPLY FOR ELECTRO-OPTICS APPLICATIONS

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ABSTRACT

This paper describes the development of high voltage power supply for electro-optics applications. The power supply consists of MOSFET driver, voltage multiplier circuit and voltage controller. A single timer 555 generates 1.3 kHz square pulse to drive the power MOSFET that connected to a standard step up transformer. By using voltage multiplier technique, the output from secondary transformer was step-up. The variable DC high voltage output is produced up to 4 kV. The input voltage as low as 12 volt is required to generate smooth and stable high voltage output.

Keywords: *HV voltage power supply, voltage multiplier and electro-optics application*

1. INTRODUCTION

Electro-optics devices were widely used for beam modulation, amplitude modulation as well as in Q-switching [1, 2 & 3]. This device required a high voltage with low current power supply (HVPS) in order to have electro-optics effect in the crystal [3, 4]. A variable HVPS is necessary for scientific research in order to have better understanding the performance of the fundamental process in electro-optics effect. In Q-switching process, a Pockels cell usually operated either half or quarter-wave voltage that in the range of 3 to 10 kV. However, the conventional power supplies in principle require bulky transformer as well as high rating capacitor in order to regulate the output voltage [5]. Toward to smaller, lighter, more efficient and low cost devices, it leads to the development of switch mode power supply (SMPS) technology [1-3, 6]. SMPS offer greater efficient compared with convention high voltage power supply because it could control the energy flow with low losses [6]. This circuit also converts low power DC to high voltage-high frequency AC [7] then converted back to high voltage DC. Voltage multiplier is the easiest key point to generate high voltage in kilovolt region [6-10] that promise simpler, compact and safe compared to convention circuits. Recently, the voltage multiplier based DC-DC converter and series-connected three-phase symmetrical multistage voltage multiplier is used to power-up X-ray power generator [9-10]. In this present paper, the high voltage power supply for electro-optic applications is discussed. This circuit uses the combination of SMPS technique and voltage multiplier to generate 4 kV output.

2. THEORY OF OPERATION

Figure 1 shows a block diagram of the developed high voltage power supply for electro-optics devices. In this development, the input signal unit provide appropriate square signal with frequency of 1.3 kilohertz. Two square pulses will drive the two MOSFETs which controlled by pulse width modulation (PWM) controller unit. The PWM controller unit is used to control pulse width of the pulse in order to modulate the pulse that used to drive two MOSFET switches. On the other hand, the negative feedback unit also is connected to PWM controller unit. This circuit was used to control the output voltage as well as the power correction of the developed circuit.

Two MOSFET switches then are used to drive 12 V to a standard center-tap step-up transformer with frequency of 1.3 kHz. Then, the step-up transformer will convert 12 V input voltage to approximately 460VAC. These output voltage were amplified by using a voltage multiplier circuit. In this voltage multiplier circuit consists of eight stages of coupled diode and capacitor that each one of them could regulate 460 VAC to approximately 500 VDC. Finally, in this development, a series of high power resistors (as voltage divider) are connected to output voltage terminal to PWM controller unit. The output of this circuit is called negative feedback signal. In the PWM controller unit, the input signal and negative feedback signal are compared. This circuit will continuously generate input signal to MOSFET switches until, the input signal is same to the signal of negative feedback.

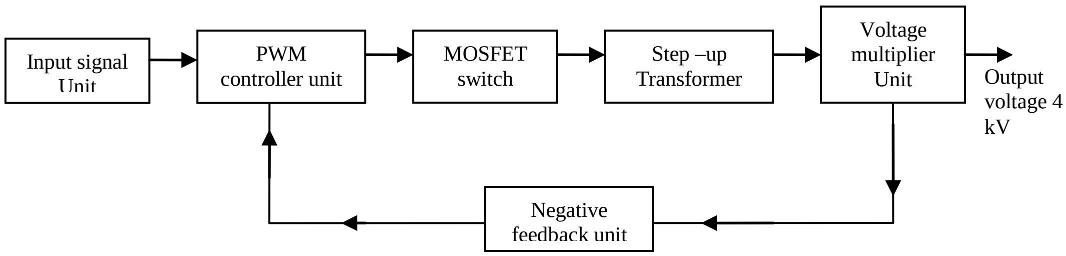

Figure 1: Block diagram of developed high voltage power supply.

3.CIRCUIT DESIGN AND COMPONENTS SELECTION

Figure 2 shows the schematic diagram MOSFET driver circuit. A timer 555 (LM 555) was used to generate 1.3 kilohertz square wave that directly connected to pin 10 and pin 5 of comparator LM 399. In this circuit, the LM 399 is used as the PWM controller. This PWM controller unit produces two square waves at different polarity (at pin 13 and pin 2) to drive two power bipolar NPN transistors, 1N3904. Following that, the output from the transistor is used to drive two MOSFETs, IR 710 which connected to both side of primary winding of the standard center –tap step-up transformer (CT: 12:460).

In order to operate this circuit, the supply voltage of 12 V with 5 A is required. The MOSFET switches will turn on and turn off the two MOSFET simultaneously. Consequently, it produces the square wave on the primary winding. As a result, the step up transformer produces 460 VAC at secondary winding. This AC voltage will be amplifed by using voltage multiplier circuit up to 4 kV.

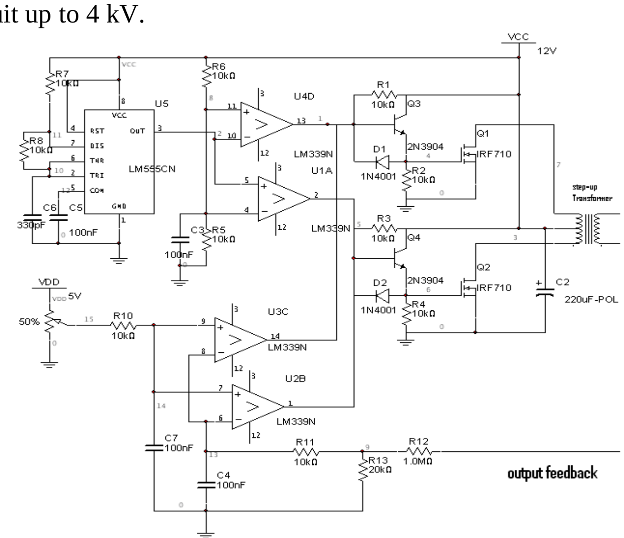

Figure 2: The schematic diagram MOSFET driver circuit

The voltage multiplier circuit consists of sixteen non-polarize high voltage capacitor with 680 nF of capacitance couple with 16 of 1N4007 diodes to form eight stages as shown in Figure 3. Each stage consists of two diodes and two capacitors which both of them have rating of 1000 V. This arrangement of voltage multiplier circuit is based on Villard cascade.

In this development, for each stage of voltage multiplier circuit will produces a smooth 500 VDC. So that, we could easily use the output from each stages depends on our applications need. If we want to amplify to more high output voltage, we could add more stages but need consider the safety factor as well as input current supply. The output voltage of Villard cascade circuit is given as [8];

$$\Delta V = \frac{1}{fC}\left(\frac{2}{3}n^3 + \frac{1}{2}n^2 - \frac{1}{6}n\right) \tag{1}$$

where, f is the input frequency, C is capacitance and n is the number of stages,

The output voltage was connected to negative feedback unit (to pin 8 and pin 6 of LM399) that consist of series resistor 16 MegaOhm couple with 20 kiloOhm. As a voltage divider, this circuit produces 5 V of feedback signals when the developed circuit generates maximum output voltage of 4 kV. A variable input voltage in the range 0 to 5 V supplied to pin 9 and pin 7 of the feedback circuit. Then, this voltage is used as the reference to the input signal from voltage divider. The output of feedback unit (pin 14 and pin 1) is directly connected to output of PWM controller circuit (pin 13 and pin 2). If the reference voltage is bigger than feedback voltage, the PWM controller unit will continuously generates square pulses. When the voltage for both reference and feedback at the same value, the PWM controller do not generates the square pulses to MOSFET switches. Consequently, amplification is stopped and the voltage is remained constant until there have voltage different of them. By adjusting the reference voltage, we could vary the output voltage of the developed circuit from 0 V to maximum of 4 kV.

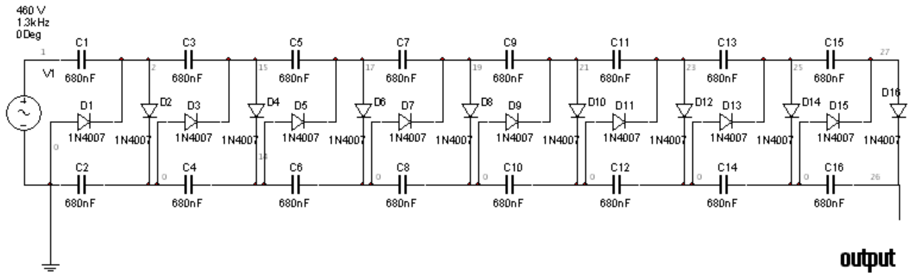

Figure 3: The schematic diagram of 8 stages voltage multiplier circuit.

4. EXPERIMENTAL SETUP

The experimental setup of measurement of developed circuit is shown in Figure 4. The developed high voltage power supply was used to supply DC voltage to the Pockels cell driver. A KD*P crystal with dimension of 10x10x50 mm^3 was utilized as a Pockels cell in the laser system. The output of the developed voltage was connected to high voltage fast switcher. These high voltage fast switcher circuit is used to switch the applied voltage to ground level. In this experiment, the output voltage was measured by using Tektronix high voltage probe model P6015 that coupled to Tektronix digital oscilloscope model TDS 3054 B. When the trigger signal is given to fast switches circuit, the applied high voltage on Pockels cell is switch to ground. All the signals regarding to this experiment was recorded and presented in this present paper.

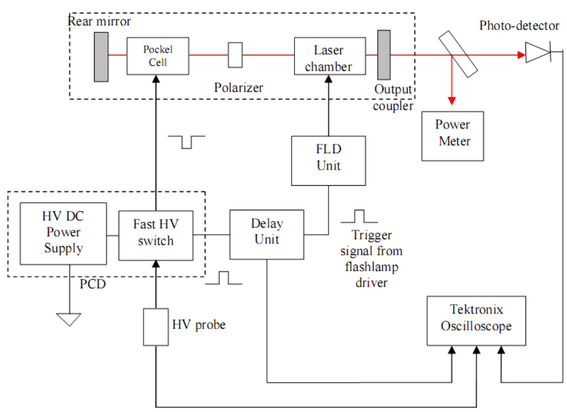

Figure 4: Experimental setup of high voltage power supply for electro-optics applications.

5. RESULTS AND DISCUSSION

Figure 5 shows the typical input signals at gate of MOSFET IR710. In this development, the two signals at different polarity with 1.3 kHz of frequency and 12 V have been applied to MOSFET. This input signal turns on the MOSFET that directly connected to the primary winding of transformer. The secondary winding of transformer converted this input signal to AC voltage of 460 VAC. The input power is approximately 60 Watt. Then, the output from the secondary winding transformer has been used as the input voltage for voltage multiplier circuit. As we have mention earlier, each stage approximately produces 500 VDC. In this development, we have used 8 stages of voltage multiplier by using Villard cascade; we were successfully produced up to 4 kV. The output current is considered low approximately 70 mA that suitable for electro-optics applications. By vary the references voltage in PWM controller unit; we should get the variable high voltage power supply.

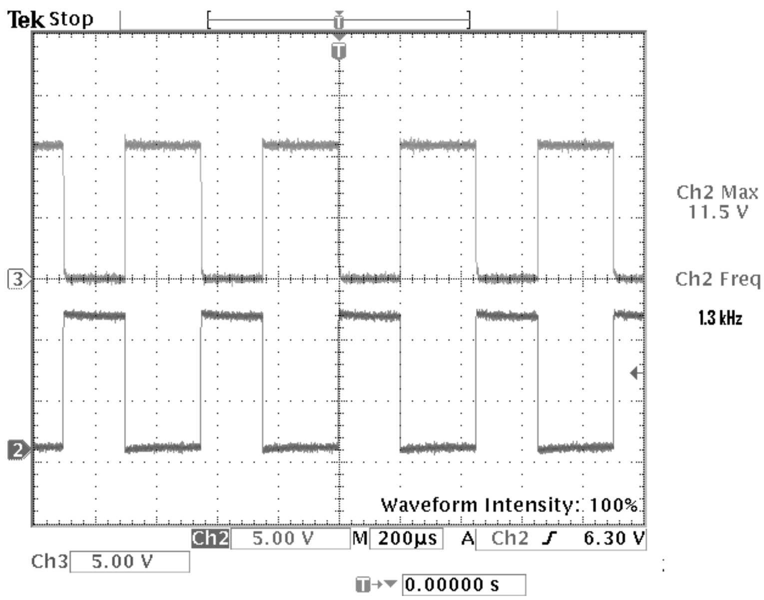

Figure 5: The input signal from PWM controller unit, two square wave signals with inversely each other at frequency of 1.3 kHz.

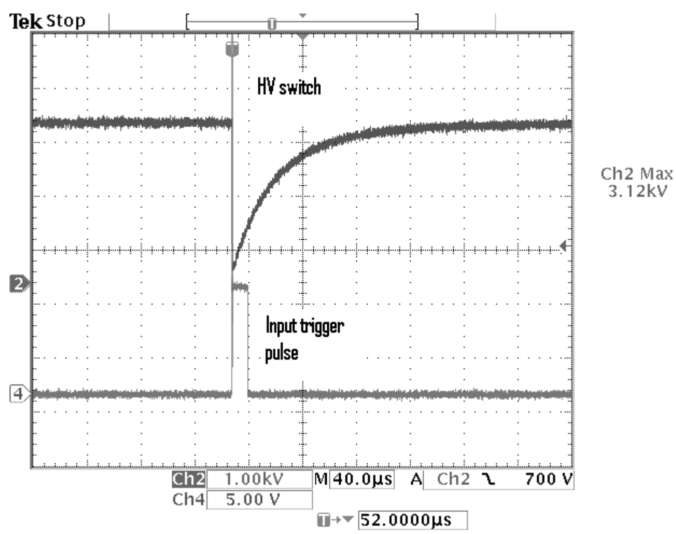

Figure 6: Typical signal of applied high voltage to KD*P crystal switching in Q-switch laser

Figure 6 illustrates the typical signal of applied high voltage switch to ground in a few nanoseconds after input trigger signal is give. The upper trace shows the applied voltage of 3.12 kV that applied to Pockels cell. This voltage was switched to ground level and raised back to normal position in 100 microseconds in time. The lower trace is shown the signal of input trigger pulse to the high voltage switcher. From this experiment, the smooth high voltage DC with high stability was produced for electro-optics application.

For convince to the end user, a display unit system was employed to this circuit. The voltage from the feedback unit was used as the input voltage for display unit. By using ADC converter and some digital manipulating, the output voltage is linearly display on the display unit. All the circuits were soldered on printed circuit board (PCB) and were placed in black box as shown in Figure 7.

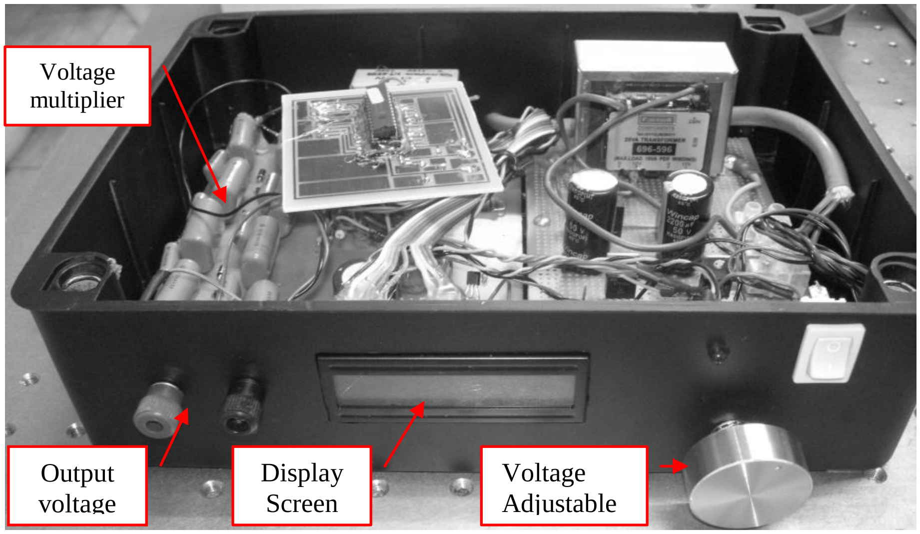

Figure 7: The picture of developed high voltage power supply for electro-optics applications.

6. CONCLUSION

As a conclusion, we have successfully developed a high voltage power supply using SMPS and voltage multiplier technique. Simple SMPS circuit and eight stages of voltage multiplier have been used to produce variable output up to 4 kV. The output current is low approximately 70 mA that suitable to electro-optics device as well as the safety precaution. This high voltage power supply has been applied to KD*P crystal as Pockels cell and the phase shift is linearly increased to the applied voltage.

7. ACKNOWLEDGMENT

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